QUARTERLY FORECASTS OF SEA AND AIR TEMPERATURES

By GEORGE F. McEWEN

Professor of Physical Oceanography

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ABSTRACT

Reliable forecasts of monthly air and sea temperatures one or several months in advance, and a general idea of the probable temperatures for a year in advance, are in great demand. In fact, attempts to provide such information for commercial purposes are made by various individual organizations, utilities, department stores, sea products companies, etc. May we expect to be able to work out such forecasts with sufficient reliability to be of commercial value?

While no adequate physical theory for guidance in such problems has been developed, it seems reasonable to assume the existence, at least in some regions, of factors which influence to a greater or less extent the temperature trend a few months in advance. In searching for the proper factors it is assumed that a composite index to them, of forecast value, is furnished by past temperatures. Proceeding empirically on this basis, the monthly temperatures are "smoothed" and adjusted in order to eliminate the irregularities which at first are regarded as accidental. Projecting these smoothed values a few months in advance in accordance with past variations, and correcting the seasonal changes for systematic errors introduced by the smoothing process, we obtain an empirical forecast. Such a procedure has been applied to observations in southern California that extend over a period of about 20 years, in order to compare the computed and observed temperatures. A very definite correlation was found; a temperature forecast 3 months in advance, by this method, departed from the actual by more than a degree in only 10 percent of the cases for sea temperatures at La Jolla. Air temperatures at Riverside were thus forecast to within 2° of the actual in about 90 percent of the cases. The success of such an empirical procedure depends upon the stability of the general temperature trends. The limited experience with this method in southern California indicates that it is of sufficient reliability to be useful economically in that region.

There is evidence of a 4-year temperature cycle, the last minimum being in 1933. The general upward trend thus indicated from 1933 to 1935 is in accord with the 3 months' forecast of higher than average temperatures for the summer of 1934.

Variation of average monthly temperatures of both the sea and air may be regarded as the result of regular, well-defined trends in causes, accompanied by accidental disturbances. Occasionally a major disturbing factor may arise and result in a correspondingly great departure of temperatures from an orderly trend. An appropriate smoothing process applied to observed monthly temperatures reduces the irregular accidental variations to a minimum. Assuming these smoothed temperatures to form a composite index of the regular trends in causes, various methods of extrapolation can be applied to predict the future smoothed temperature; and its comparison with smoothed values of observed temperatures tests the validity of the assumptions. Corrections to eliminate systematic effects of the smoothing process, especially the reduction of seasonal amplitude, should be calculated for the predicted smoothed temperatures. The difference between values thus corrected and observations will be due to lack of agreement between actual conditions and the underlying assumptions, and may have a regular

trend to which are added accidental departures which cannot be eliminated.

The smoothed value of the middle one of a series of 21 terms, calculated by the Spencer 21-term formula,[1] was used in this study. If, as is usual, an inspection of the smoothed observed values indicates a tendency toward repetition of certain sequences, the series can be extended beyond the last observation by selecting an earlier sequence agreeing approximately with the last one. It is desirable to make more than one such selection. Then the smoothed series can be extrapolated beyond the last observation:

Making use of only the smoothed results terminating with the last observation, various methods of two-way extrapolation can be applied; the simplest is to use the

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[1] Spencer's 21-term formula (Whittaker and Robinson, Calculus of Observations, p. 290; Rietz, Handbook of Mathematical Statistics, p. 59) applied to a third degree polynomial function, with equal intervals of the independent variable, does not change the original values. In general it tends to give a smooth graduation. If applied to a sine function, it reduces the amplitude and thus tends to suppress cyclical variations. However, this tendency is most pronounced for small periods, especially those less than 10. To apply this method:
(1) Compute progressive sums, 7 at a time.
(2) Compute progressive sums of these results, 5 at a time.
(3) Compute progressive sums of these results, 5 at a time.
(4) Compute the weighted progressive sums of these results, 7 at a time, with the following weights: −1, 0, 1, 2, 1, 0, −1.
(5) Divide the last result by 350, which equals 7×5×5×2, to obtain the smoothed value. Exactly 21 terms are required for each smoothed value, which corresponds to the middle term of the series.
The weighted progressive sums, 7 at a time, can also be calculated first, then the two, 5 at a time in succession, and finally the progressive sums, 7 at a time. To illustrate the computations, both methods are here applied to the same series:

	(7)	(5)	(5)	Weighted sums (7)	Smoothed values		Weighted sums (7)	(5)	(5)	(7)	Smoothed values
52						52					
72						72					
60						60					
72	420					72	160				
60	428					60	112				
52	416	2064				52	96	584			
52	416	2020				52	84	560			
60	384	1980	9924			60	132	552	2780		
60	376	1944	9780			60	136	544	2708		
60	388	1916	9688			60	104	540	2648		
40	380	1920	9644	18952	54.14	40	88	512	2628	18952	54.14
52	388	1928	9656	19012	54.32	52	80	500	2652	19012	54.32
64	388	1936	9692			64	104	532	2732		
44	384	1956	9756			44	124	568	2804		
68	396	1952	9856			68	136	620	2840		
60	400	1984				60	124	584			
56	384	2028				56	132	536			
52	420					52	68				
56	428					56	76				
48						48					
80						80					
76						76					

Various special methods can be used for smoothing the 10 values at the beginning and end. One method is explained in "The Smoothing of Time Series", by F. R. Macaulay, National Bureau of Economic Research, No. 19, 1931.

multipliers −1 and 2 for the last 2 values, and the multipliers 1, −2, and 1 for the 3 corresponding values in the preceding year. For example, table 1, lines 2 and 3, presents smoothed monthly air temperatures at San Diego for 1932 and 1933, where the last month of observations was September 1933. Observations in the year 1921 were used to extend the series. The extrapolated value in line 4 for October was calculated as follows:
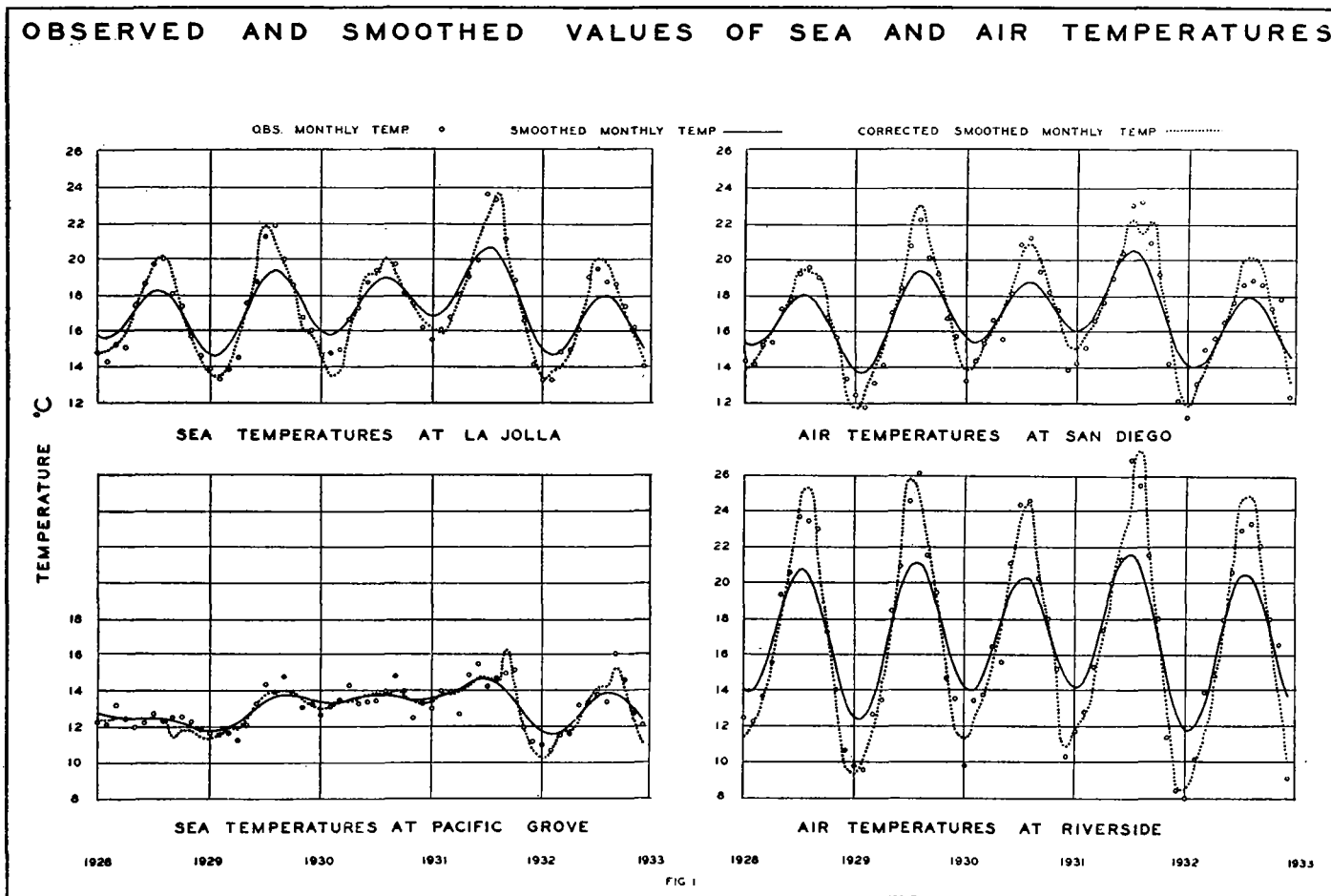
$$17.95 - 2(17.50) + 16.62 - 17.32 + 2(\underline{17.12}) = 16.18$$

TABLE 1.—*San Diego air temperatures*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
[2]	14. 17	14. 11	14. 39	15. 28	16. 33	17. 28	17. 86	17. 95	17. 50	16. 62	15. 58	14. 58
[3]	13. 83	13. 54	13. 72	14. 39	15. 32	16. 28	17. 00	17. 32	17. 12	16. 47	15. 52	14. 56 [1921]
[4]								17. 23	16. 92	16. 18	15. 28	14. 42
[5]	Forecast: from line 4									17. 10	15. 30	13. 10
[6]	Observed									16. 89	16. 33	12. 83

integral. Divide the monthly values into two equal groups, one centering about M_1 and the other about M_2. Then find the ratios $(O-M_1) \div (S-M_1)$ and $(O-M_2) \div (S-M_2)$ for each month, where O=average monthly value. To obtain any corrected value, multiply $(S-M_1)$ or $(S-M_2)$ by the value of the ratio R corresponding to that month. Original monthly temperatures shown by the points in figure 1 should be compared with the full lines representing smoothed values, and the dotted lines representing smoothed values corrected for curvature.

Of the various groups of multipliers that can be used for extrapolating, four are shown in figure 2, which also presents data on the reliability of smoothed values forecast 3 months in advance.

A summary of forecasts from 1 to 4 months in advance is shown by figure 3, where a vertical line is drawn after the last month of observations used in making the forecasts represented by the portion of the full line extending

OBSERVED AND SMOOTHED VALUES OF SEA AND AIR TEMPERATURES

OBS. MONTHLY TEMP ∘   SMOOTHED MONTHLY TEMP ———   CORRECTED SMOOTHED MONTHLY TEMP ··········

SEA TEMPERATURES AT LA JOLLA

AIR TEMPERATURES AT SAN DIEGO

SEA TEMPERATURES AT PACIFIC GROVE

AIR TEMPERATURES AT RIVERSIDE

FIG 1

The same multipliers were applied to values 1 month later, *using 16.18*, to obtain 15.28 for November; and so on. The agreement between the values thus extrapolated and the values of the extended series checks the selection of the sequence. These extrapolated smoothed values corrected for curvature, and entered in the next line, are forecasts of monthly temperatures; the temperatures later observed are entered in the last line for comparison. The curvature corrections were made by means of a table computed as follows:

Smooth the average monthly values for the whole series of years. In general there will be two times in the cycle at which the average monthly values M_1 and M_2 equal the smoothed values. These times may not be

to the next vertical line. The distribution of the differences between these observed and forecast values is presented in table 2.

TABLE 2.—*Distribution of the 93 departures between temperature forecasts and observations*

Departure (° C.)	0. 4	0. 8	1. 2	1. 6	2. 0	2. 4	2. 8
Percent less than the departure	27	51	68	80	84	87	90

An examination of the mean monthly air temperatures predicted 3 months in advance over a period of 16 years shows that for Riverside, in 55 percent of the cases the error was within 0.5° C; in 74 percent of the cases the error was within 0.7° C.; in 90 percent of the cases the error was within 1.1° C.

The unusually high temperatures at Riverside and especially Sierra Madre during October and November 1933 were caused by local dynamic heating; that is, by a downflow of air in that region, which was heated as it was compressed. This condition, which is associated with the barometric pressure distribution, should be given special attention in making such temperature forecasts, observations. Experience has shown that the departure of the seasonal minimum temperature of the smoothed curve from the sum-12 curve tends to a different average value near low points of the latter from that at high points. This is also true of the departure of seasonal maximum temperatures. Accordingly, projecting the sum-12 curve, and plotting the departure of seasonal

EXTRAPOLATION OF SMOOTHED TEMPERATURES AND TESTS OF THEIR ACCURACY

FOUR GROUPS OF FACTORS FOR COMPUTING THE SMOOTHED TEMPERATURE 1 MO. IN ADVANCE

Group 1:
+1	-2	+1
-1	+2	X

Group 2:
-1	-1	+2
-1	-1	+2
+2	+2	4X

Group 3:
-1	+2	-1
+2	-4	+2
-1	+2	X

Group 4:
-1	+3	-3	+1
+1	-3	+3	X

DEPARTURES FROM SMOOTHED TEMPERATURES OF THOSE FORECAST 3 MO. IN ADVANCE

PERCENTAGE LESS THAN TABULATED DEPARTURE

DEPARTURE	°25	°50	°75	1°00	1°25	1°50
RIVERSIDE AIR	19	45	63	78	88	94
LA JOLLA SEA	42	69	87	97	100	

CORRELATION OF SMOOTHED RIVERSIDE AIR AND LA JOLLA SEA TEMPERATURES WITH FORECAST

MEAN – SMOOTHED TEMPERATURES (Riverside Air)

MEAN – THREE MONTHS FORECAST		-2.1/-1.5	-1.5/-.9	-.9/-.3	-.3/.3	.3/.9	.9/1.5	1.5/2.1	
3.9	3.3						1		1
3.3	2.7					2	0		2
2.7	2.1				1	0	1	1	3
2.1	1.5			1	2	3	4	0	10
1.5	.9			2	5	12	4	1	24
.9	.3			9	13	13	3		38
.3	-.3			6	15	13			34
-.3	-.9		4	10	16	4			34
-.9	-1.5	1	3	19	8	2			33
-1.5	-2.1	2	4	6	0				12
-2.1	-2.7	3	2	1	1				7
-2.7	-3.3	1							1
		7	13	54	61	47	14	3	199

MEAN – SMOOTHED TEMPERATURES (La Jolla Sea)

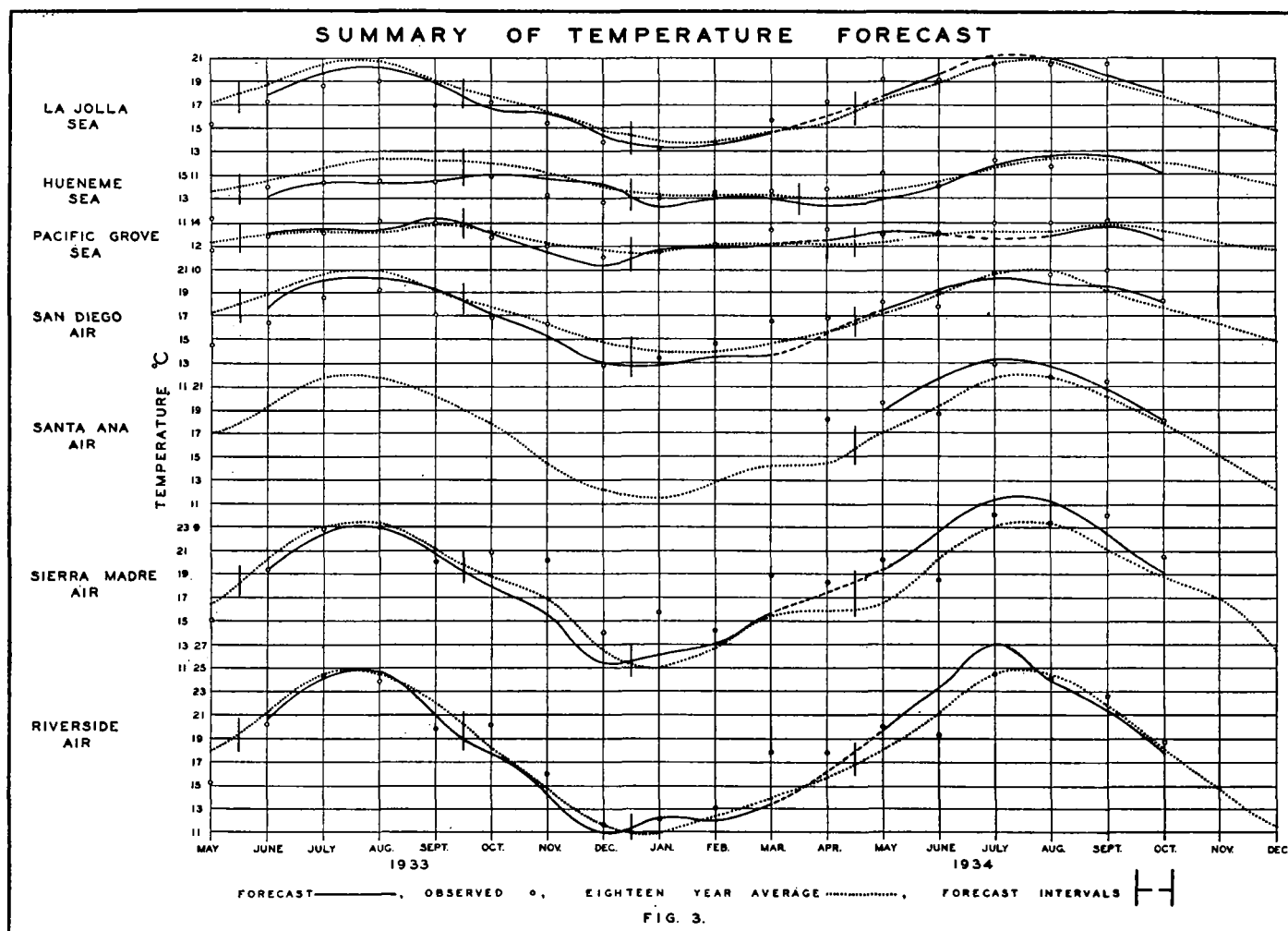| MEAN – THREE MONTHS FORECAST		-2.7/-2.1	-2.1/-1.5	-1.5/-.9	-.9/-.3	-.3/.3	.3/.9	.9/1.5	1.5	
2.7	2.1						2			2
2.1	1.5					6	5	1		12
1.5	.9				2	17	3			22
.9	.3				15	23	3			41
.3	-.3			2	32	8				42
-.3	-.9		8	13	8	1				30
-.9	-1.5	1	4	15	1					21
-1.5	-2.1	3	1	2						6
-2.1	-2.7	5	2							7
-2.7	-3.3	2	2							4
		2	11	15	32	58	55	13	1	187

FIG. 2

especially during September, October, and November, but was not taken into account in this study.

The following supplementary graphical procedure, providing a general "outlook" of temperatures over longer periods of 6 months, has been helpful: Eliminate the seasonal variation from the smoothed temperatures by computing averages of successive sums of 12 observations, and plot the corresponding temperature curve, called the "sum-12" curve, using all of the available minimum and of seasonal maximum temperatures estimated for the plotted values of the sum-12 curve, provides a generalized forecast.

In general, the various mathematical methods of forecasting outlined in this paper appear to be useful tools when applied with judgment, and checked for consistency. The limited experience with this procedure in Southern California indicates sufficient reliability to be of commercial value in that region.

SUMMARY OF TEMPERATURE FORECAST

FORECAST————, OBSERVED o, EIGHTEEN YEAR AVERAGE ···············, FORECAST INTERVALS ⊢—⊣

FIG. 3.

AN INTERNATIONAL COMPARISON OF STANDARD BAROMETERS

By S. P. FERGUSSON

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For the measurement of short-period or day-to-day changes of atmospheric pressure and for almost all other purposes of meteorology and engineering, simple mercurial barometers of the "station" type having tubes about 6 mm in diameter are sufficiently accurate. But when pressures in different parts of the world are to be compared, and changes during long periods of time analyzed, instruments of greater precision become necessary; consideration must be given to the materials of which they are made and the slight variations of condition (chiefly of the vacuum) occurring in almost all barometers, even those of superior construction, through periods of many years. The only method of securing uniform, comparable records is that of comparing working standards, station or observatory barometers in current use, with "normal" or primary standards, the vacuum of which can be controlled and measured with high precision under "laboratory" conditions. Primary standards are costly and must be operated by trained physicists; but their importance is indicated by the design and use of several excellent examples in various countries of Europe.

In America, until recently, the sole dependence for international comparisons of pressures has been a few large-bore instruments of the Fortin type adjusted to agree with normals at the Kew Observatory, England, or similar instruments in France and Germany. One of the best examples is that of the importation, in 1878, by the United States Signal Service, under the most careful supervision, of 10 barometers by Adie of London, 4 of which are still used as standards by the United States Weather Bureau; another is the purchase by Professor Rotch of similar instruments by Hicks of London (no. 818 in 1885, no. 872 in 1887, and no. 1019 in 1892), for use at Blue Hill Observatory; and a third is that of an English barometer employed recently by the Canadian Meteorological Office in a comparision with the official standard of Canada; all of these instruments were certified at Kew. The Adie barometers and Hicks nos. 818 and 1019 have 12 mm tubes; that of no. 872 is 15 mm in diameter.

When Blue Hill Observatory was opened in 1885 the standard barometer was Green no. 2677, an instrument of the "station" type having a 6 mm tube, corrected to agree with the Signal Service standard, which, as stated, was that of Kew Observatory determined by means of the Adie barometers of 1878. Since January 1886 the standard of pressure has been that of Kew based upon the Hicks barometers of 1885, 1887, and 1892.

Differences developing among the barometers at Blue Hill, and between the standards of the Weather Bureau and Blue Hill during the period 1885 to 1892, led to the